CASE FILE COPY

TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 635

TANK TESTS OF A MODEL OF ONE HULL OF THE SAVOIA S-55-X FLYING BOAT - N.A.C.A. MODEL 46

By John M. Allison
Langley Memorial Aeronautical Laboratory

Washington
February 1938

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE NO. 635

TANK TESTS OF A MODEL OF ONE HULL OF THE SAVOIA S-55-X FLYING BOAT - N.A.C.A. MODEL 46

By John M. Allison

SUMMARY

A model of one of the twin hulls of the Italian Savoia S-55-X flying boat (N.A.C.A. model 46) was tested in the N.A.C.A. tank according to the "general" method. The data obtained from the tests cover a broad range of speeds, loads, and trims and are given in nondimensional form to facilitate their use in applying this form of hull to any other flying boat or comparing its performance with the performance of other hulls. The results show that the resistance characteristics at best trim of this model are excellent throughout the speed range. In order to compare the performance of the S-55-X hull with that of model 35, a pointed-step hull developed at the N.A.C.A. tank, the data are used in the computations of a take-off example of a twin-hull, 23,500-pound flying boat. The calculations show that the S-55-X hull has better take-off performance.

INTRODUCTION

The program of work at the N.A.C.A. tank includes the testing of models of hulls of successful foreign and domestic flying boats for the double purpose of obtaining information as to their relative water performances and of insuring that future development will be concentrated on the forms showing the greatest promise. An investigation of this kind is of value in that it shows how designers of various countries use different methods to achieve satisfactory performance. The first model of this series was that of a two-step flying boat considered fairly representative of British practice (reference 1).

Another model of the series is that of one of the twin hulls of the Savoia S-55-X flying boat (N.A.C.A. model 46), the lines of which were obtained from the Italian Government. These flying boats (see figs. 1 and 2) are well known for their mass-formation flight across the Atlantic Ocean in 1933.

An unusual feature of this hull is the form of the bottom of the forebody, which is slightly concave transversely. In an investigation of flat and V planing plates (reference 2) it was found that, as the dead rise of the V plate was decreased toward zero, the resistance decreased. For that reason, the S-55-X hulls with their slightly concave bottoms were expected to have very low water resistance in the planing region.

A flat planing surface has been found to reduce the height of the wake profile (reference 3). In the case of hulls, one would expect the water coming off a flat forebody to be less likely to add resistance by striking the afterbody. A concave bottom also helps to reduce the height of the transverse bow wave. It was believed that these features, incorporated in the hulls of the S-55-X, would make them run cleanly at both low and high speeds.

DESCRIPTION OF MODEL

The principal lines of N.A.C.A. model 46, made 1/5.25 full size of one of the S-55-X hulls, are shown in figure 3 and the offsets are given in table I. The body plan shows the concave bottom of the forebody at the step. This concavity extends forward of the step for a distance equal to almost two beams and terminates in a straight horizontal transverse section at the point where the keel line crosses the chine line in profile. From that point forward the sections of the bow increase in sharpness of V, ending in a low forefoot. The dead rise of the afterbody increases with distance aft of the step, giving a wind in the bottom surface. For convenience, the depth of the model was made less than was shown on the plans of the original and the top was made flat instead of rounded.

The model was made of laminated mahogany with a minimum shell thickness of 1 inch. It was finished in gray enamel, wet-sanded to give a smooth surface.

The particulars of the model and of the full-size flying boat are as follows:

	Model	Full-size
Length:		
Over-all - - - - - - - - -	74.48 in.	32 ft. 7 in.
Of forebody to main step	37.03 in.	16 ft. 2.4 in.
Maximum beam - - - - - - - -	14.24 in.	6 ft. 2.76 in.
Gross load - - - - - - - - -	81.5 lb.	11,800 lb.
Get-away speed - - - - - - -	48.5 f.p.s.	75.9 m.p.h.
Center of moments forward of step - - - - - - - - - -	0.03 in.	0.16 in.
Center of moments above keel	11.31 in.	4 ft. 11.4 in.
Depth of step at chine - - -	1.23 in.	6.46 in.
Depth of step at center line	0.60 in.	3.15 in.
Concavity at step - - - - - - -	0.22 in.	1.155 in.
Angle of keel forward of step to base line - - - - -	$3^\circ\ 21'$	$3^\circ\ 21'$
Angle of keel aft of step to base line - - - - - - - - - -	$1^\circ\ 15'$	$1^\circ\ 15'$
Trim at rest	0.6°	0.6°

Linear ratio of model to full-size - - - 1/5.25

Beam:
- Percentage of over-all length - - - - 19.11
- Percentage of forebody length - - - - 38.48

Forebody:
- Percentage of over-all length - - - - 49.7

Center of moments, distance forward of the step:
- Percentage of over-all length - - - - 0.04
- Percentage of forebody length - - - - 0.086

Center of moments, distance above the keel:
- Percentage of over-all length - - - - 15.2
- Percentage of forebody length - - - - 30.5

APPARATUS AND PROCEDURE

The N.A.C.A. tank and its equipment are described in reference 4. The model suspension and the method of measuring the trimming moment have since been changed; the altered arrangement is shown in reference 5.

The model was tested according to the general method. This type of test includes a number of constant-speed runs in which the trim is kept constant while the load on the water is changed at each speed. As many trims as necessary were tried in order to obtain the best trim at any speed or any condition of loading within the test range. Readings taken for each point were: resistance, trimming moment, and draft.

A free-to-trim test was made with the initial load, the get-away speed, and the fore-and-aft location of the center of gravity of the model corresponding to the specifications of one of the twin hulls of the full-size flying boat at the stated gross load. As the vertical position of the center of gravity had not been supplied with the lines, it was necessary to estimate it. In this test, the trimming-moment spring was freed, allowing the model to trim about the towing point. Resistance, trim, and rise of the center of gravity were read from zero to get-away speeds. A calibrated hydrofoil supplied the lifting force, simulating that of the wing of the full-size flying boat.

RESULTS

Test data.- Figures 4 to 10 show the trimming moment and resistance plotted against speed with load (Δ) as a parameter. These curves are used in deriving the nondimensional coefficients of resistance and moment at best trim throughout the speed range. Each figure represents the data for one trim (angle between the base line and the horizontal). All trimming moments are measured about the center of moments shown in figure 3, moments that tend to raise the bow being considered positive.

The static trimming moments and drafts for different trim angles and loads, as determined by experiment on the model, are given in figures 11 and 12, respectively. These curves make it possible to determine the trim and load water line at rest for any desired combination of load and position of center of gravity without laborious calculation.

Figure 13 shows load, resistance, load-resistance ratio, rise, and trim plotted against speed for the free-to-trim runs. The load on the model at rest was 81.5 pounds, corresponding to a gross load of 11,800 pounds on one of the hulls of the S-55-X. The angle of attack of the hydrofoil was adjusted to make the model take off at 48.5 feet per second, corresponding to a full-scale get-away speed of 75.9 miles per hour (10 percent above the reported stalling speed).

Nondimensional results.- The number of independent variables in the test data may be reduced by considering only the trim corresponding to minimum resistance for selected speeds and loads. The resistance and trimming moment are determined at this "best trim." The results, reduced to nondimensional form, are shown in figures 14 to 17.

The nondimensional coefficients are defined as follows:

Load coefficient, $C_\Delta = \dfrac{\Delta}{wb^3}$

Resistance coefficient, $C_R = \dfrac{R}{wb^3}$

Trimming-moment coefficient, $C_M = \dfrac{M}{wb^4}$

Speed coefficient, $C_V = \dfrac{V}{\sqrt{gb}}$

where Δ is the load on water, lb.

R, resistance, lb.

w, specific weight of water, lb./cu. ft. (63.5 for this test).

b, beam of hull, ft.

M, trimming moment, lb.-ft.

V, speed, ft./sec.

g, acceleration of gravity, ft./sec.^{2}

Any other consistent system of units may be used.

DISCUSSION

Resistance at best trim.- The resistance of model 46 was unusually low for all speeds and loads. Figure 15 shows that increase of resistance with speed in the high-speed range is small. In the curves of Δ/R against C_Δ (fig. 18) it can be seen that the load-resistance ratio at the hump stays above 4.5, even at a load coefficient of 1.0, representing a large overload on one of the twin hulls of the S-55-X. At speeds above the hump, the values of Δ/R are high, probably on account of the rather large depth of step and the shape of the forebody under surface, which together act to keep the water coming off the step from striking the afterbody.

Trimming-moment at best trim.- The curves of trimming-moment coefficient against speed coefficient (fig. 17) show a high positive peak near the hump speed. This peak would indicate excessive trimming moment in the full-scale flying boat. Moving the center of moments forward to a position corresponding to that used in conventional American hulls would greatly reduce these positive moments. Some time after the tests were completed, the correct position of the center of gravity was obtained from the Italian Government; the magnitudes of the positive trimming moments obtained in this test were found to be only about 5 percent greater than if the center of moments had been at the center of gravity. The thrust moment would, of course, reduce the maximum positive moments shown.

Best trim.- Figure 16 shows how the best trim τ_o, varies with C_V. It should be noted that, at the negative trims shown, the under surface of the forebody is running at a positive angle, since the angle between it and the base line is 3° 21'. For example, at $C_\Delta = 0.95$ and $C_V = 2.7$, the attitude of the forebody is about 9.5°, whereas τ_o is only 6.25°. At $C_\Delta = 0.05$ and $C_V = 7.0$, the angle of the forebody is about 3°, corresponding to $\tau_o = -0.5°$.

A study of figures 13 and 16 shows that the trim of the model is too high throughout the take-off range. The trim of the full-scale flying boat would be nearer best trim than the comparison indicates, however, because of the thrust moment tending to bring the bow down.

Spray characteristics.- Figures 19(a) and 19(b) show model 46 running at planing speeds, with the bow well out of the water. The sheet of water coming off the step is kept low, and very little of it strikes the afterbody, even with the 40-pound load. The trim -1°, is near best trim.

In figures 19(c) and 19(d) the speed is near the hump, and the trim is near best trim. In 19(c) the bow is well out of the water and the height of the blister is kept down by the concave under surface of the forebody. A stern roach is plainly visible. Figure 19(e) shows the stern view of the model under the same conditions of speed, load, and trim. In figure 19(d), the bow of the model is far down in the water and is pushing some water forward; the bow blister is broken up into spray and thrown high after leaving the chine. The load in this case would represent about 44 percent overload on the S-55-X. Figure 19(f) shows the stern view of the same condition. The sternpost is seen to be riding heavily in the water, and the stern roach is higher and nearer the sternpost than in figures 19(c) and 19(e).

Take-off example.- The following example compares the take-off performance of hull forms 46 and 35 when applied to twin-hull flying boats having the following specifications:

Gross load - - - - - - - - - - -	23,500 lb.
Wing area - - - - - - - - - - -	1,000 sq.ft.
Geometrical aspect ratio - -	10.0
Effective aspect ratio - - -	20.0
Stalling speed (flaps down 30°) - - - - - - - - -	68.3 m.p.h. (100.2 f.p.s.)
Parasite-drag coefficient, C_{D_p} (not including profile drag of wing) -	0.02

The tapered airfoil has simple split flaps of 0.6 span and 0.2 chord, deflected 30° during take-off. Hull form 46 has a low best trim at high speeds and does not take off quickly enough with the hull at best trim unless assisted by a large angle of wing setting or by the use of flaps. The lift and drag curves of the airfoil with the flaps down 30° are shown in figure 20.

Model 35 is a pointed-step hull having a dead rise of 15° at the step and a V-shaped forebody and afterbody. When the tank tests (reference 6) were made, it had the best resistance characteristics of any model tested in the N.A.C.A. tank up to that time.

In this example, both flying boats have the same beam and were assumed to run at best trim from the start until all the load was air-borne. The angle of wing setting was chosen to give approximately minimum air plus water resistance at 85 percent of the stalling speed, this method of selection having been found satisfactory in previous take-off examples. The angles of wing setting with respect to the forebody keel were made the same for each of the flying boats. This arrangement makes the angle of attack of the straight part of the forebody keel the same for each hull when the flying boats are flying at the same speed. One hull will then probably be about as near its optimum cruising attitude as the other.

The curves for air drag, total resistance, and propeller thrust are shown in figure 21. The hypothetical thrust curve gives about 25 percent excess thrust at the hump. A summary of the take-off particulars of the two flying boats is given in the following table:

Hull form	46	35
Beam, ft. (of each of the twin hulls)	6.56	6.56
Load coefficient at rest, C_{Δ_0}	0.65	0.65
Angle of attack α, deg. (of the wing at 85 percent of stalling speed)	9.0	11.0
Angle of wing setting, deg. (with respect to forebody keel)	6.0	6.0
Take-off time, sec.	60.9	66.5
Take-off run, ft.	3,885	4,320

The hull with model 46 lines has lower resistance throughout most of the take-off but flies off at a slightly greater speed than the one with model 35 lines. Both hulls have exceptionally low resistance at all speeds. The effective dead rise of each is somewhat lower than is customary, and the landing loads are known to be severe for the S-55-X hull.

CONCLUSIONS

Analysis of the tank test data shows that a twin hull of the Savoia S-55-X flying boat has the following characteristics:

1. Exceptionally low water resistance at best trim at all speeds and loads tested.

2. Excessively large maximum positive trimming moments at best trim, with the center-of-moments position as used in the test.

3. At normal loads, exceptionally clean running at all speeds.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., January 12, 1938.

REFERENCES

1. Shoemaker, James M.: A Complete Tank Test of a Model of a Flying-Boat Hull - N.A.C.A. Model No. 16. T.N. No. 471, N.A.C.A., 1933.

2. Shoemaker, James M.: Tank Tests of Flat and V-Bottom Planing Surfaces. T.N. No. 509, N.A.C.A., 1934.

3. Sottorf, W.: Experiments with Planing Surfaces. T.M. No. 739, N.A.C.A., 1934.

4. Truscott, Starr: The N.A.C.A. Tank - A High-Speed Towing Basin for Testing Models of Seaplane Floats. T.R. No. 470, N.A.C.A., 1933.

5. Allison, John M.: Tank Tests of a Model of the Hull of the Navy PB-1 Flying Boat - N.A.C.A. Model 52. T.N. No. 576, N.A.C.A., 1936.

6. Shoemaker, James M., and Bell, Joe W.: Complete Tank Tests of Two Flying-Boat Hulls with Pointed Steps - N.A.C.A. Models 22-A and 35. T.N. No. 504, N.A.C.A., 1934.

TABLE I - Offsets for N.A.C.A. Model 46 Flying-Boat Hull (Inches)

Station	Distance from F.P.	Distance below base line: Keel	B1* 1.80	B2 3.60	B3 5.40	Chine	Deck	Half-breadths: Chine	WL1** 5.10	WL2 2.70	Deck
F.P.	0	3.19	<—— St. line ——> Stations 0 to 5			3.19	0	0			0
0	1.13	5.53				4.05		1.98	<—— St. line ——>		1.05
0	2.25	6.34				4.80		3.06		2.57	1.86
1	4.01	7.02				5.73		4.16	4.05	3.58	2.83
3	7.28	7.53				6.94		5.43	5.15	4.76	4.02
5	10.28	7.72				7.63		6.10	5.73	5.35	4.70
7	13.28	7.90	7.90	7.94	8.00	8.05		6.54	6.10	5.69	5.11
9	16.66	8.08	8.09	8.14	8.21	8.31		6.80	6.32	5.93	5.40
11	21.16	St. line 8.35	8.36	8.41	8.48	8.57		6.99	6.46	6.08	5.61
13	25.66	8.61	8.62	8.67	8.74	8.83	St. line	7.06	<—— St. line ——> Stations 13 to 26		5.73
15	29.66	8.85	8.86	8.91	8.98	St. line 9.07		7.10			5.78
17	33.18	9.05	9.06	9.11	9.18	9.27		7.12			5.81
19 F	37.03	9.28	9.29	9.34	9.41	9.50		7.12			5.80
19 A		8.68	<—— St. line ——>			8.27		6.95			
22	41.98	8.58	<—— St. line ——> Stations 22 to 36			7.98		6.89			5.77
24	45.99	8.50				St. line 7.74		6.81			5.75
26	50.49	8.40				7.46		6.69			5.64
28	54.99	8.30				7.18	0	6.40			5.39
30	59.49	St. line 8.20				6.94	0.07	5.85			4.80
32	63.64	8.11				6.82	0.93	5.02			3.96
34	66.99	8.03				6.90	1.82	3.80	3.40	2.79	2.48
36	70.71	7.95				7.20	2.70	2.14	1.33	0	0
A.P.	74.48	7.86				7.86		0			

*Distance from center line (plane of symmetry) to outtock (section of hull surface made by a vertical plane parallel to plane of symmetry)

**Distance from base line to water line (section of hull surface made by a horizontal plane parallel to base line)

Figures 1,2.- Views of Savoia S-55-X flying-boat.

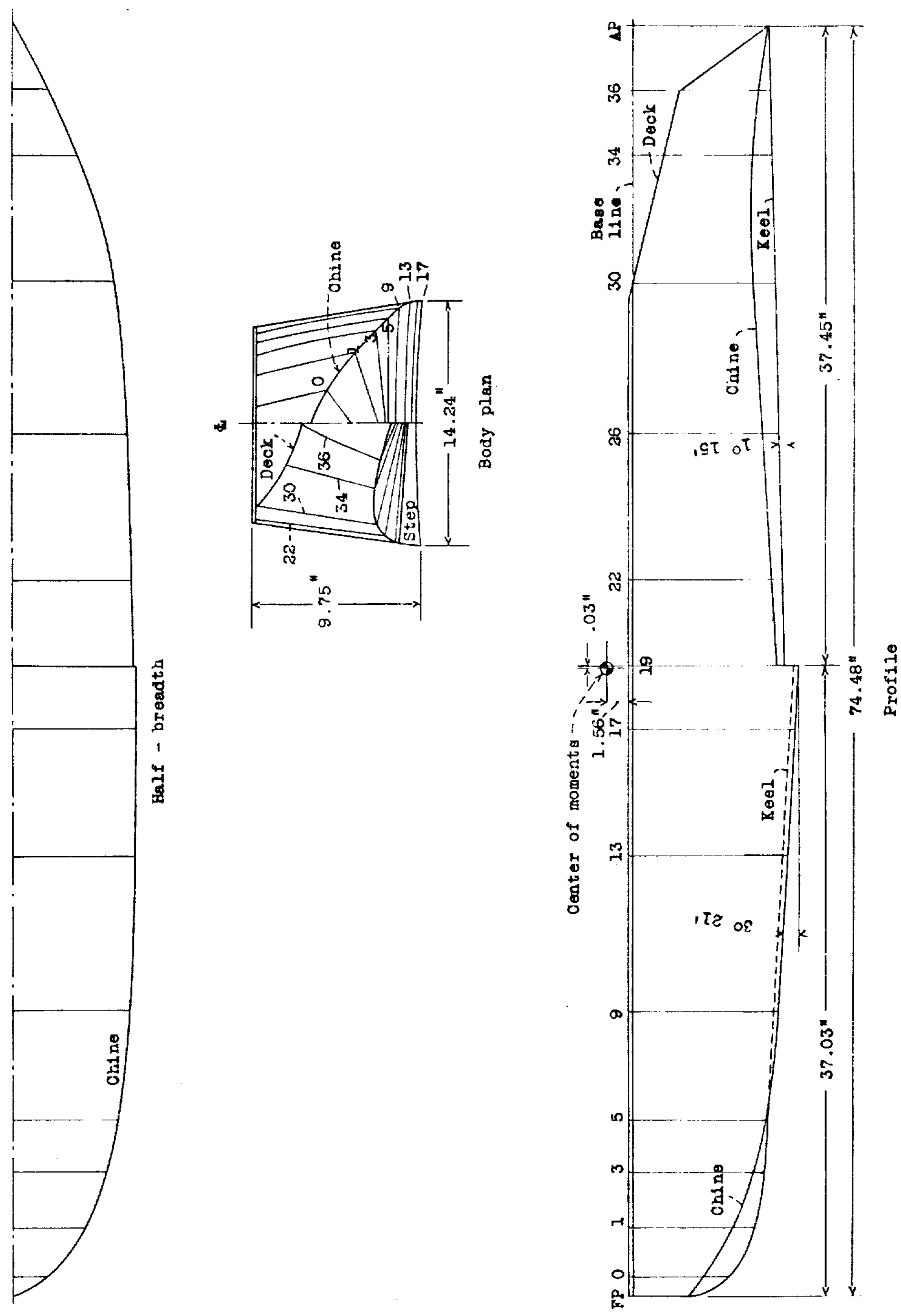


Figure 3. - Lines of N.A.C.A. model 46.

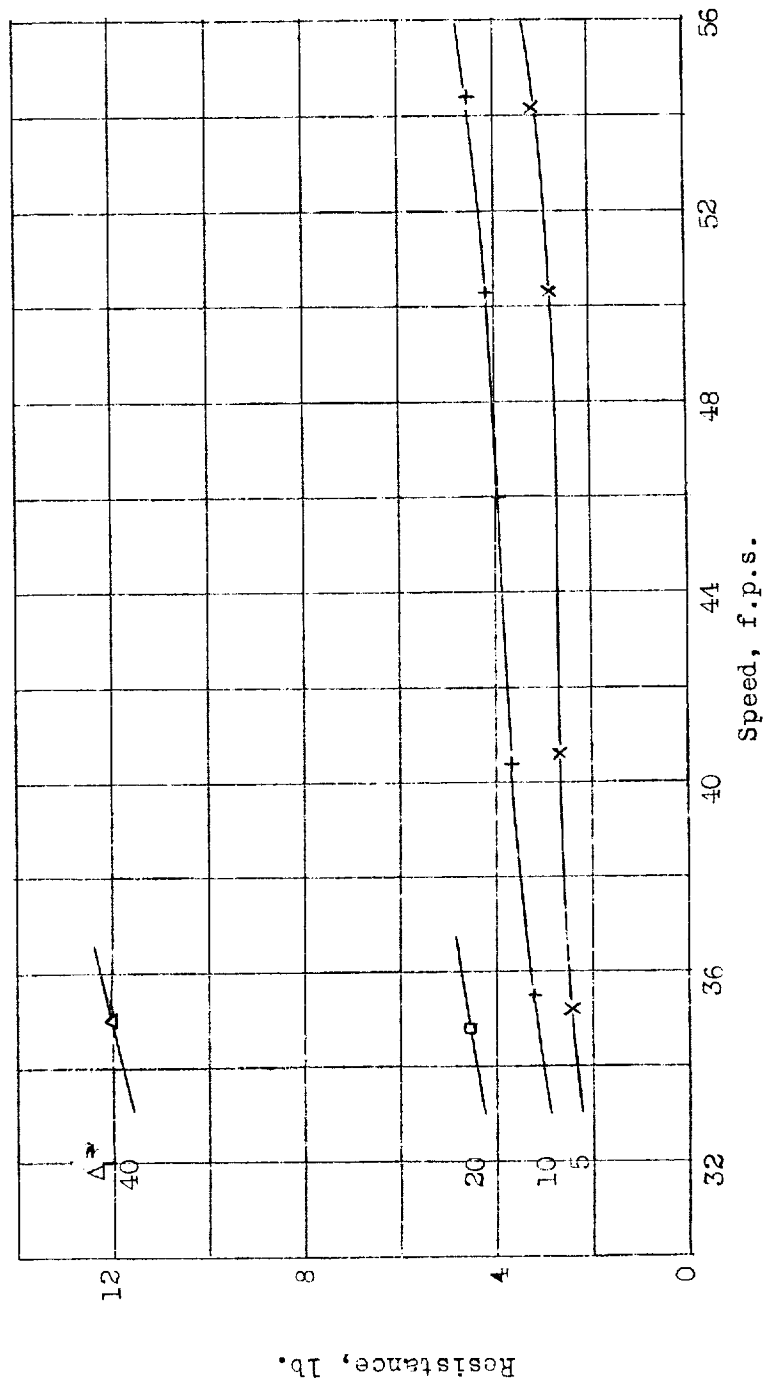


Figure 4. — Model 46. Resistance, $\tau = -2^{\circ}$
(a)

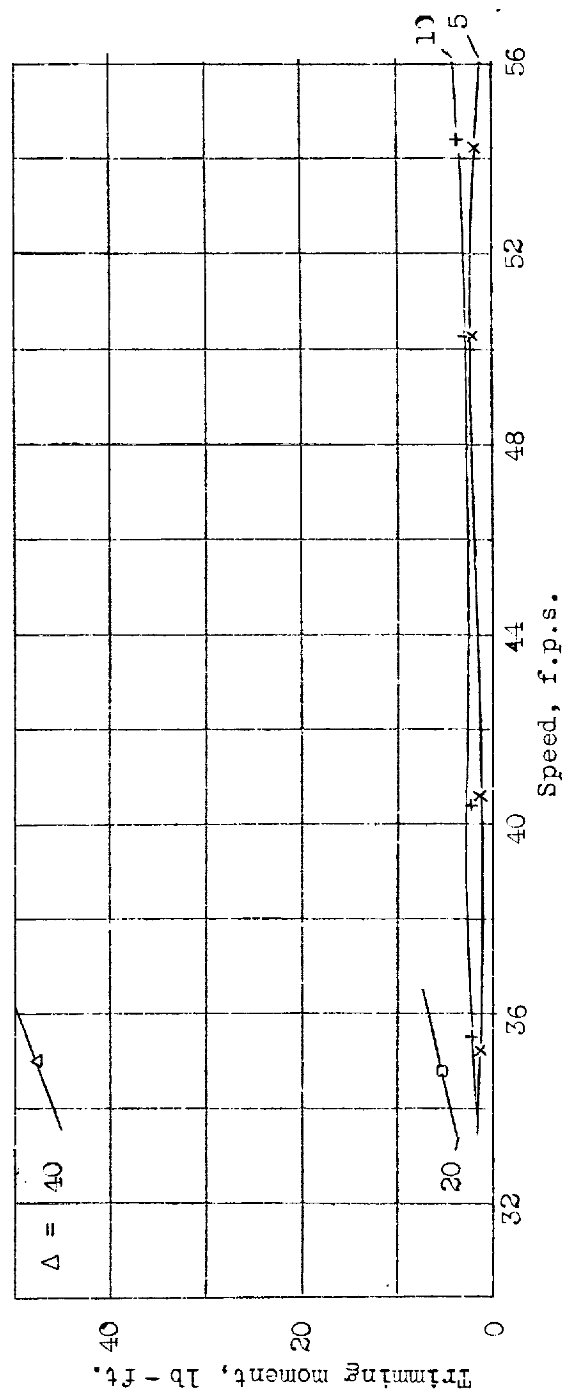


Figure 4. (b) Trimming moment, $\tau = -2^{\circ}$. Model 46.

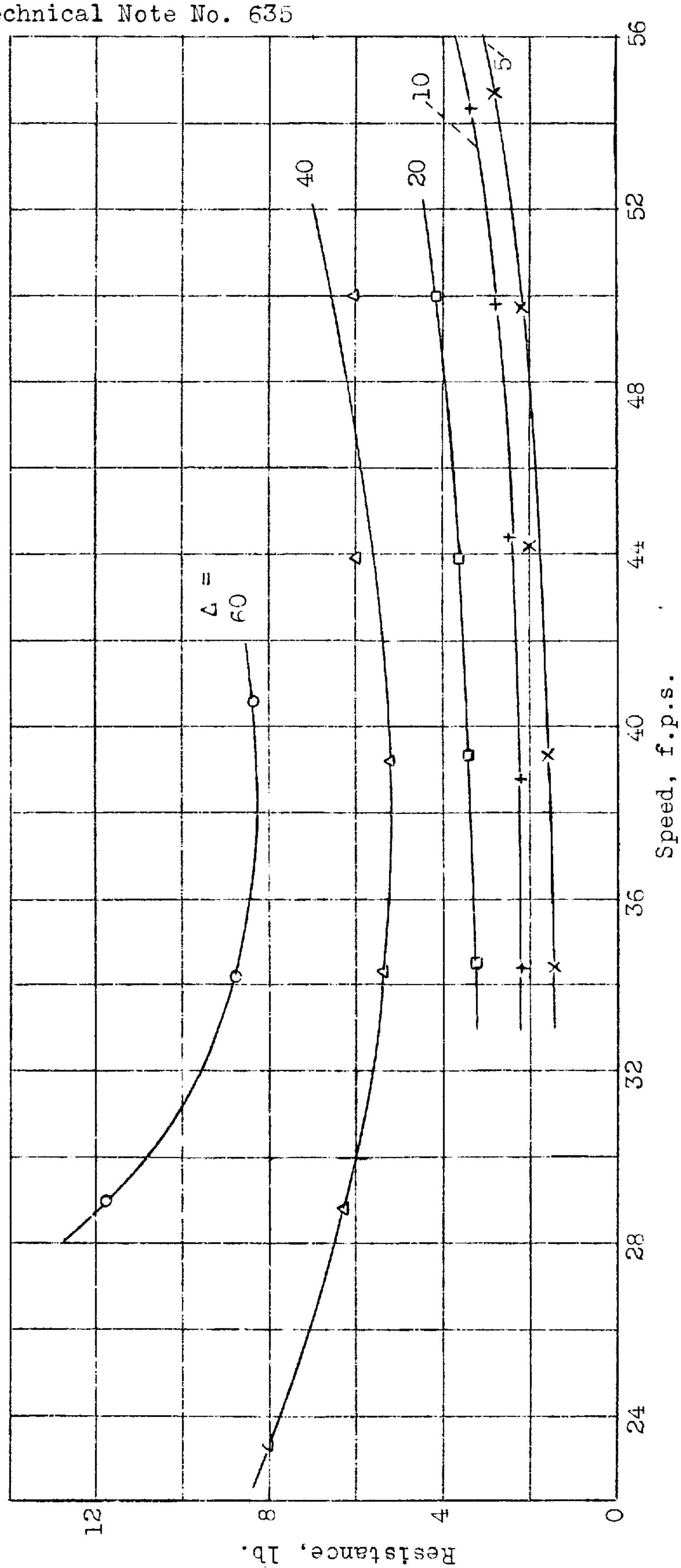


Figure 5. - Model 46. Resistance, $\tau = -1^{\circ}$
(a)

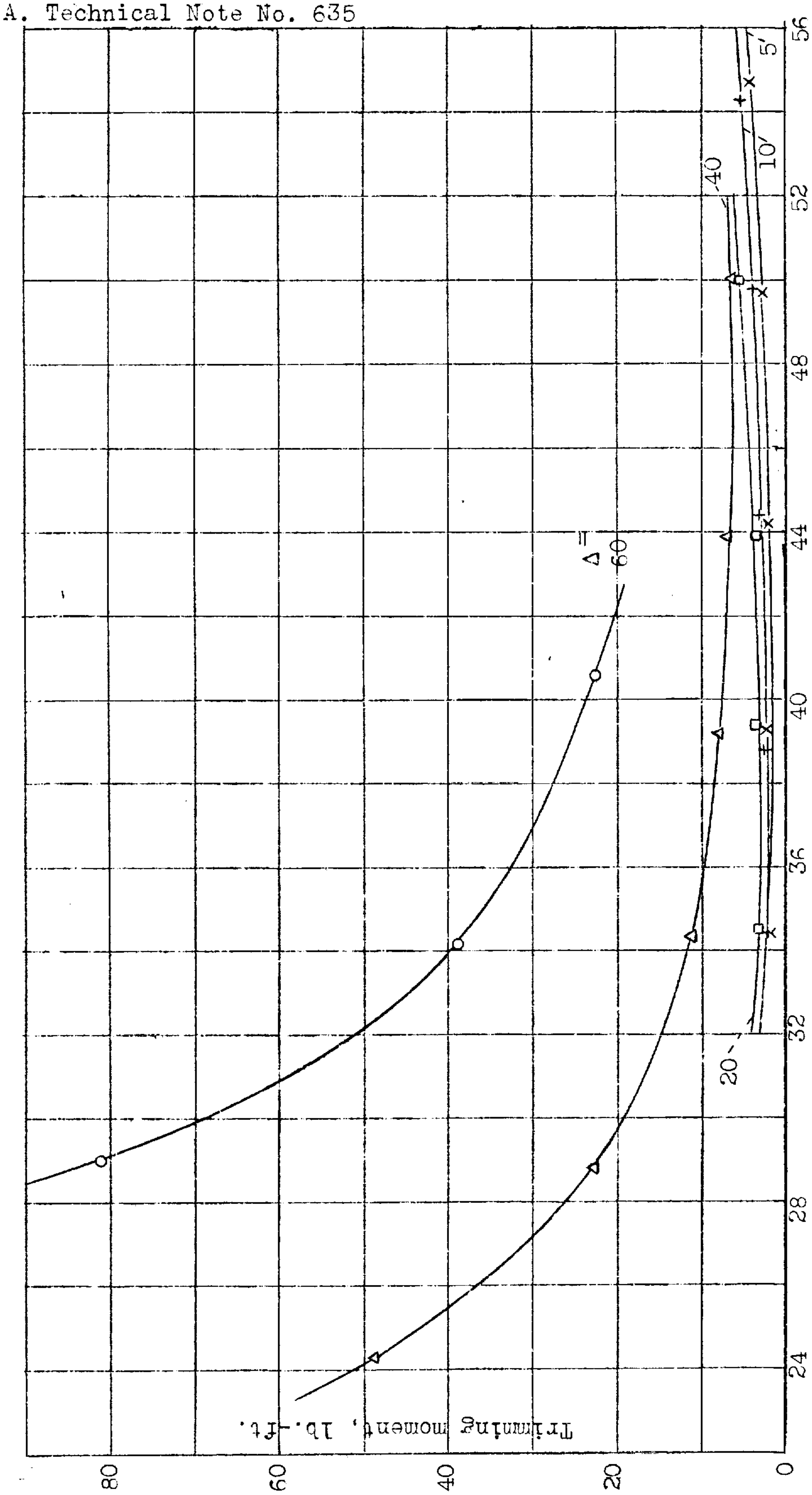


Figure 5(b). - Model 46. Trimming moment, $\tau = -1^{\circ}$

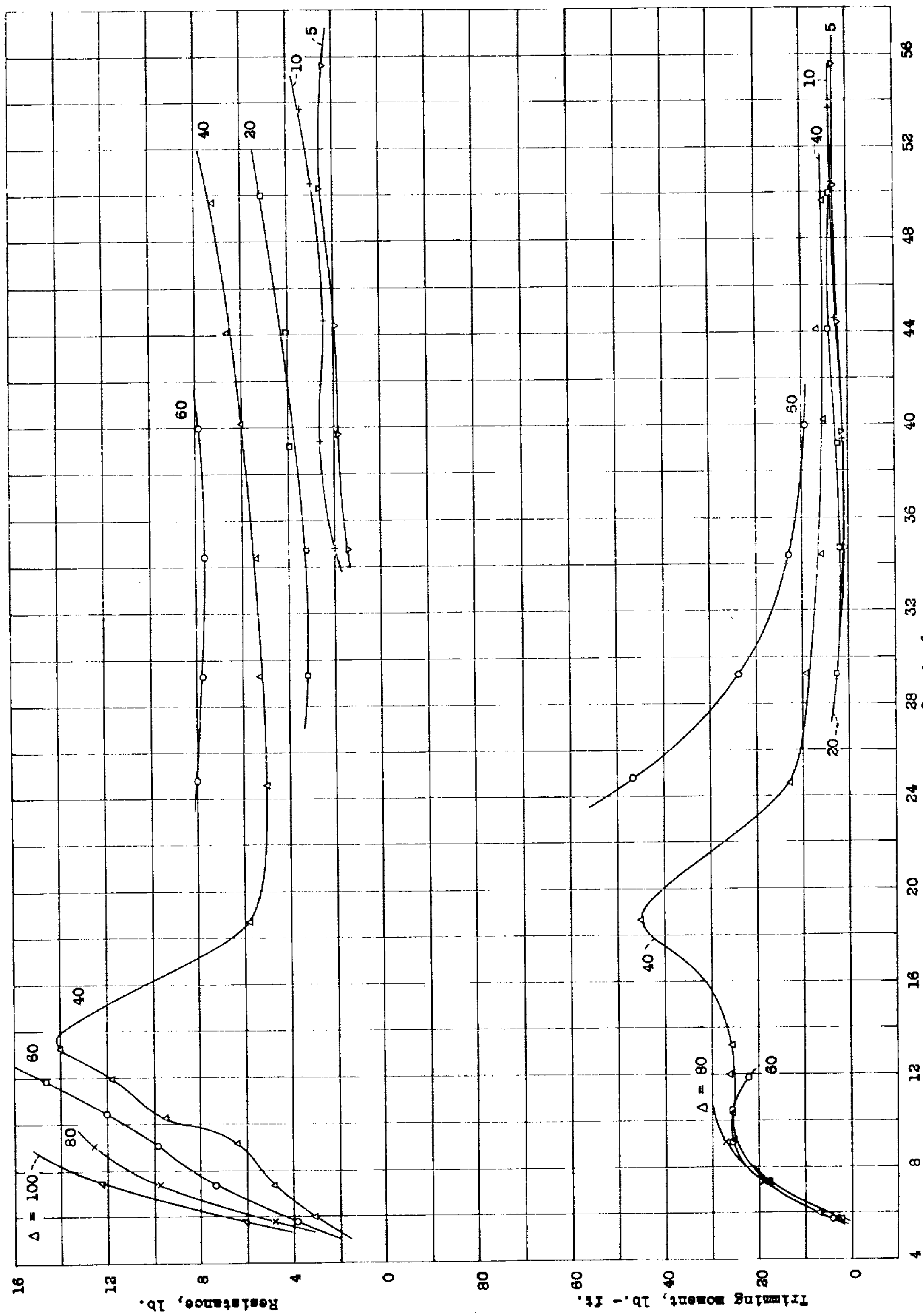


Figure 6. - Model 46. Resistance and trimming moment. τ = 1°

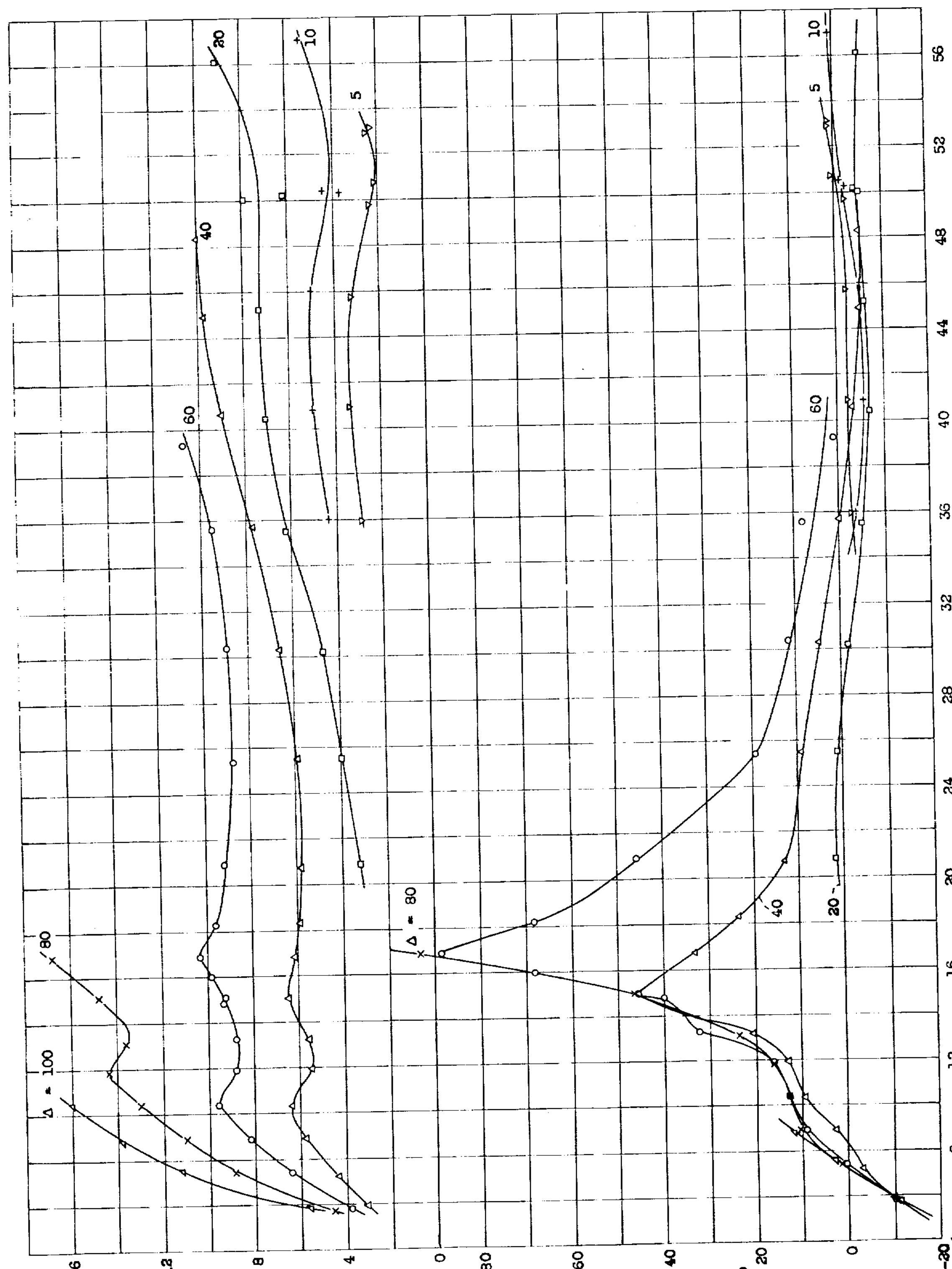


Figure 7.- Model 46. Resistance and trimming moment. τ = 3°

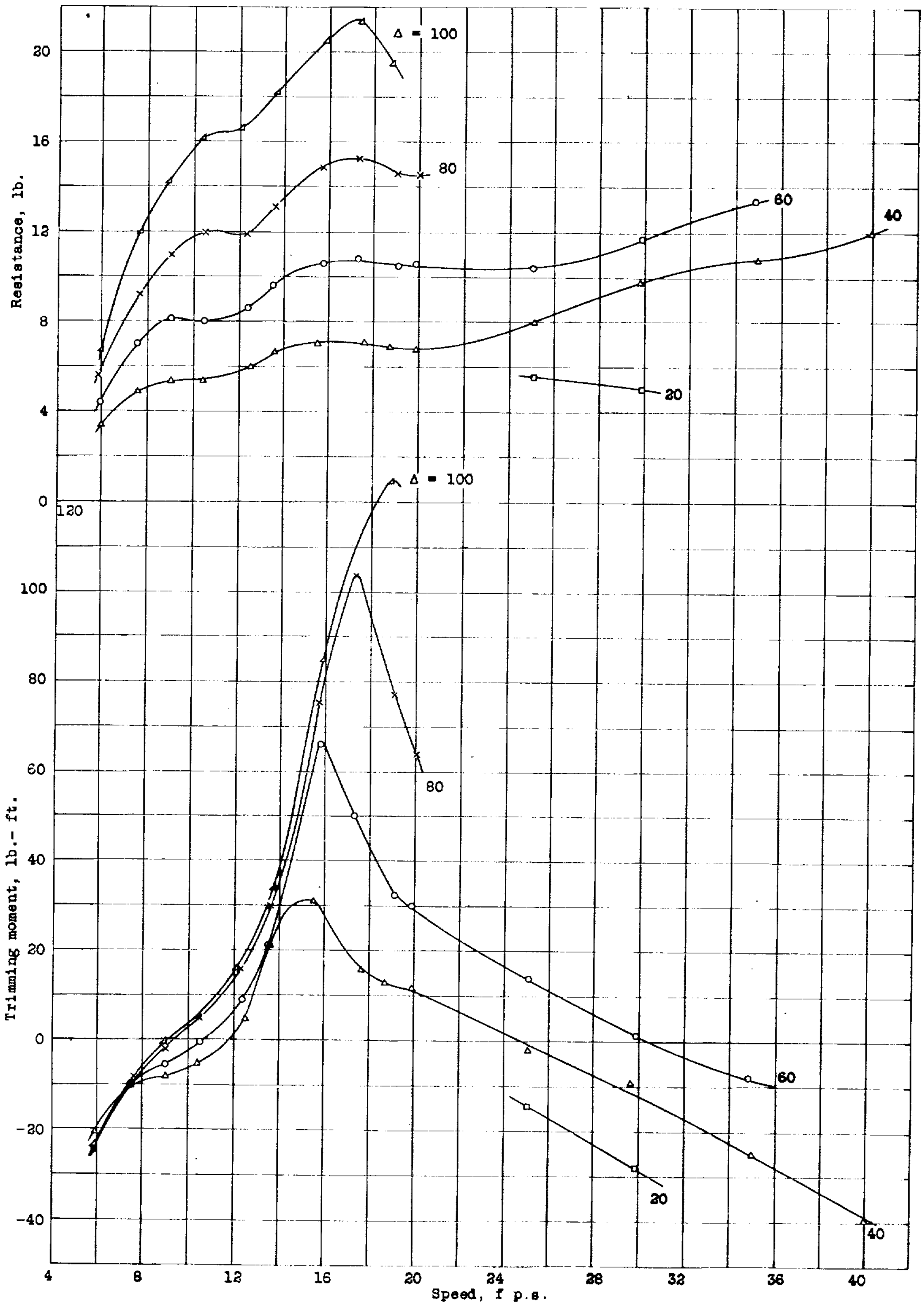
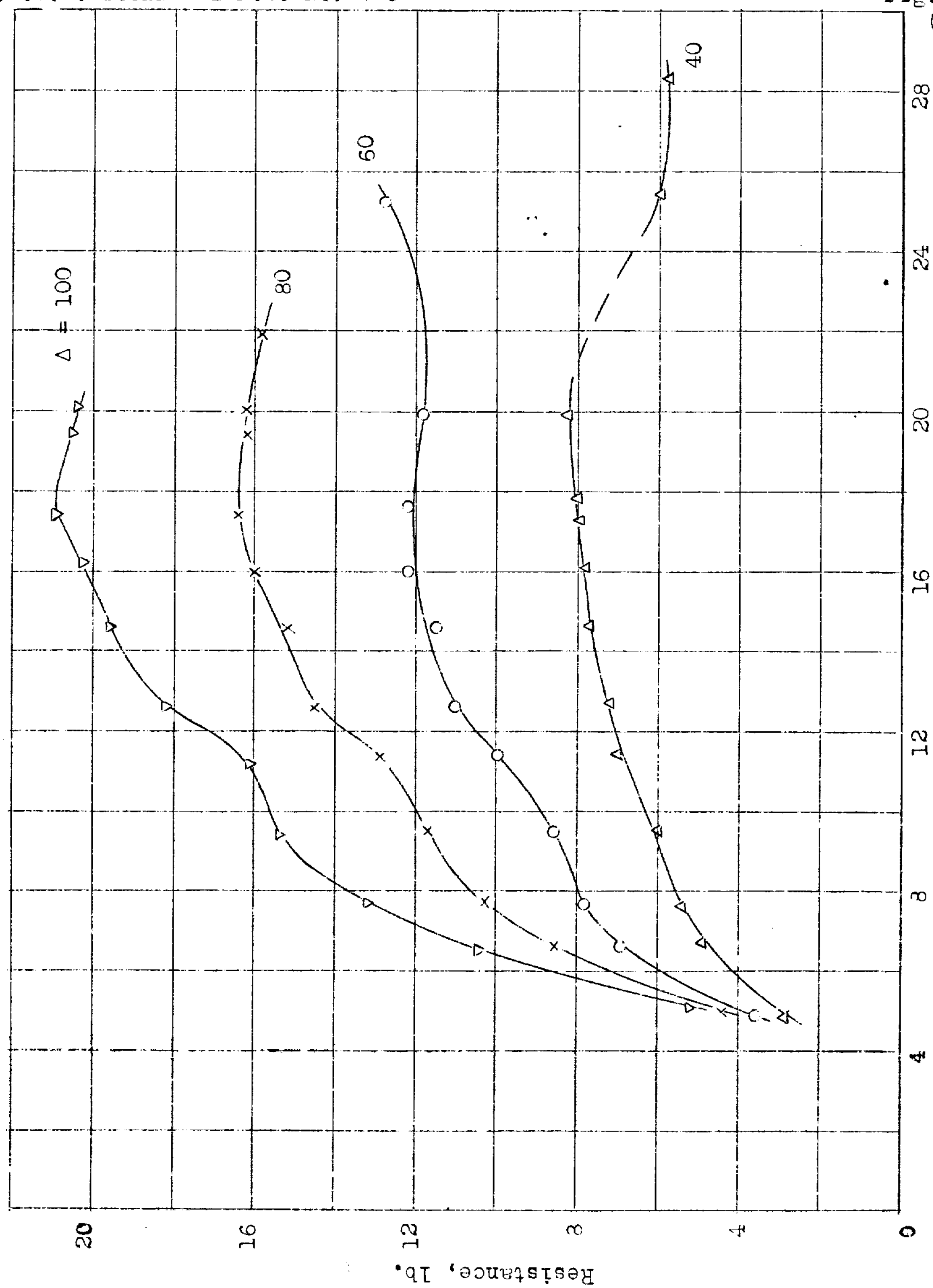


Figure 8. – Model 46. Resistance and trimming moment, $\tau = 5^{\circ}$



Speed, f.p.s.

Figure 9. _ Model 46. Resistance, $\tau = 7°$
(a)

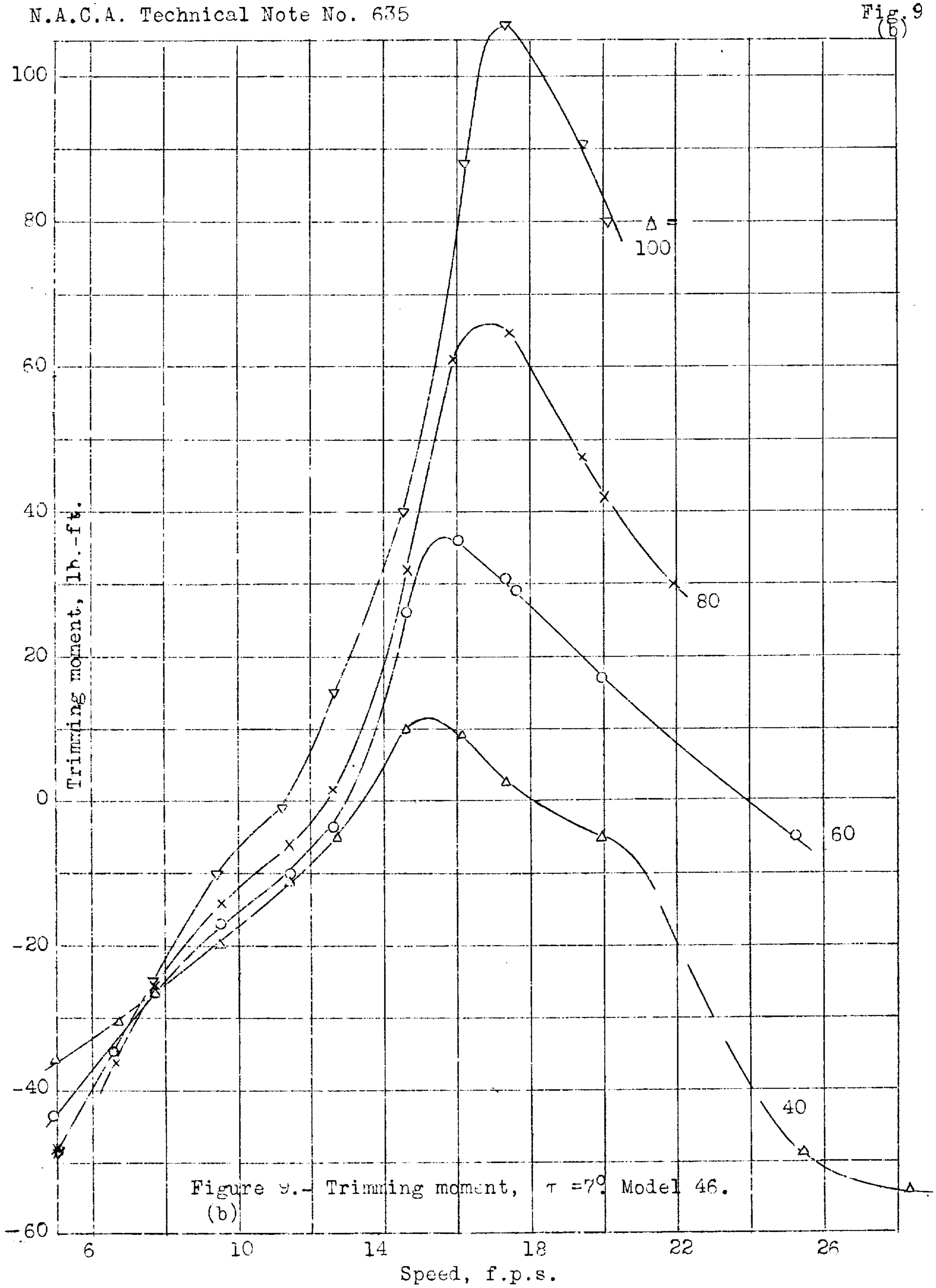


Figure 9.- Trimming moment, τ = 7°, Model 46. (b)

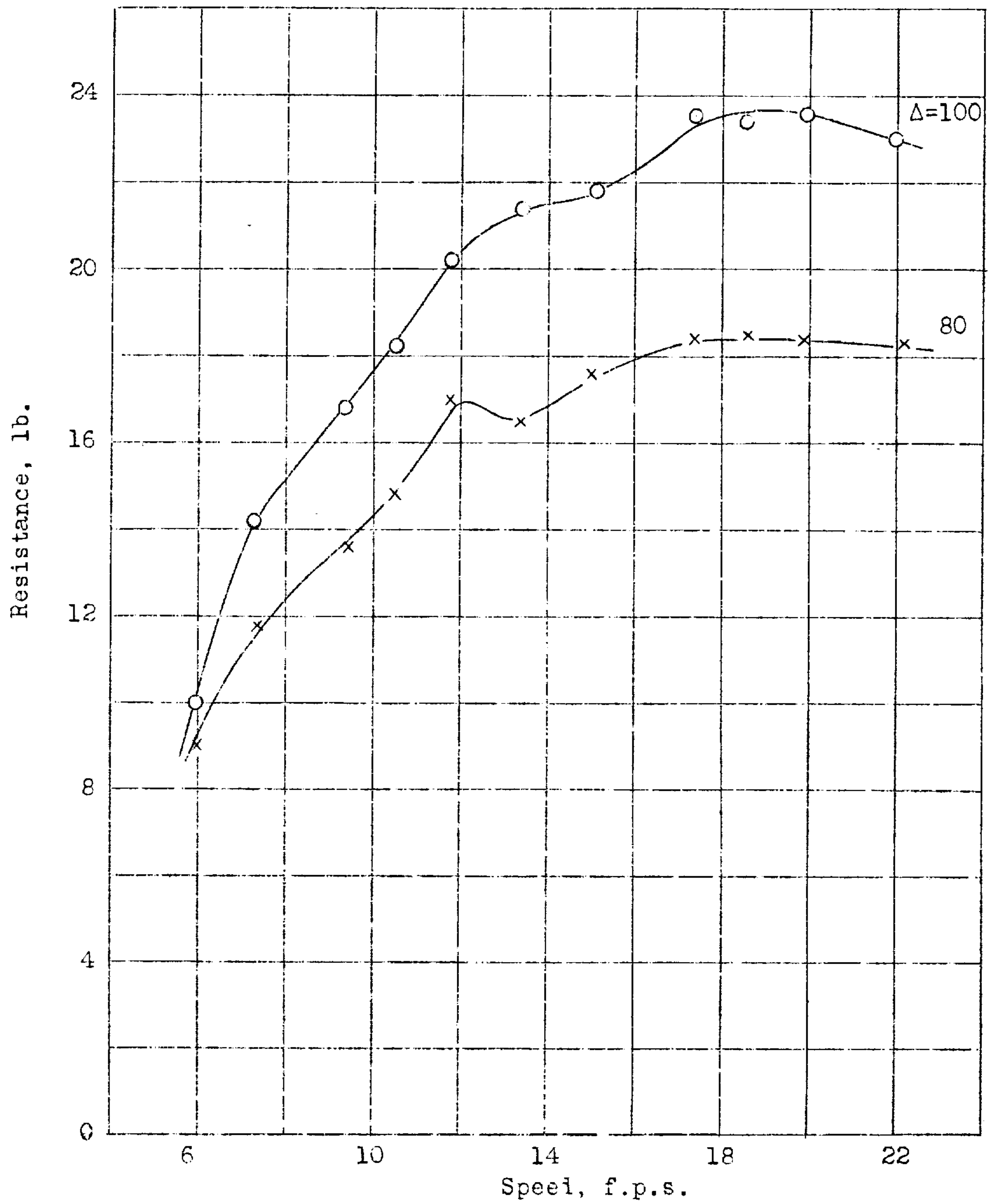


Figure 10.- Model 46. Resistance, $\tau = 9^{o}$
(a)

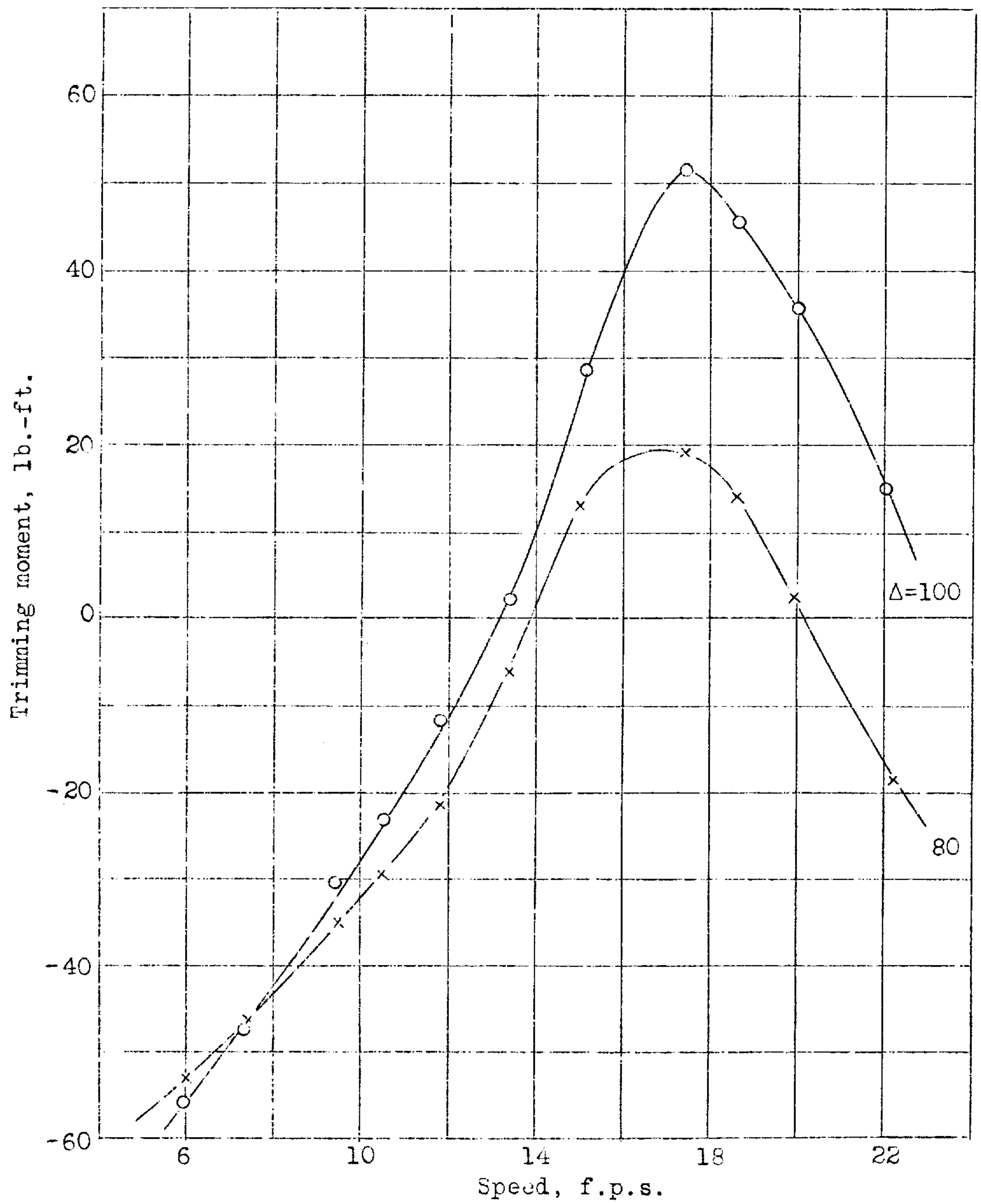


Figure 10.- Model 46. Trimming moment, $\tau = 9^{\circ}$
(b)

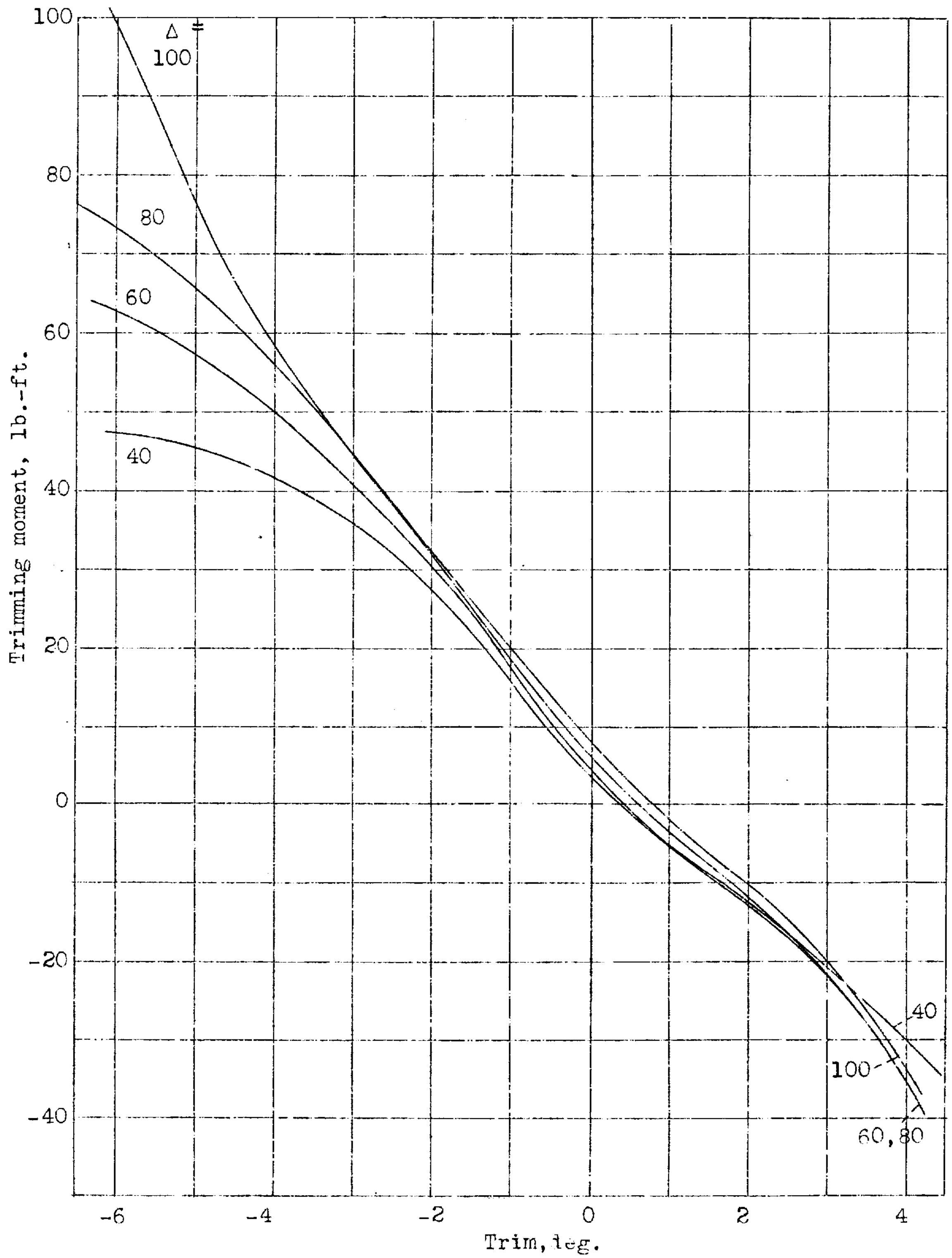


Figure 11.- Model 46, Static trimming moments.

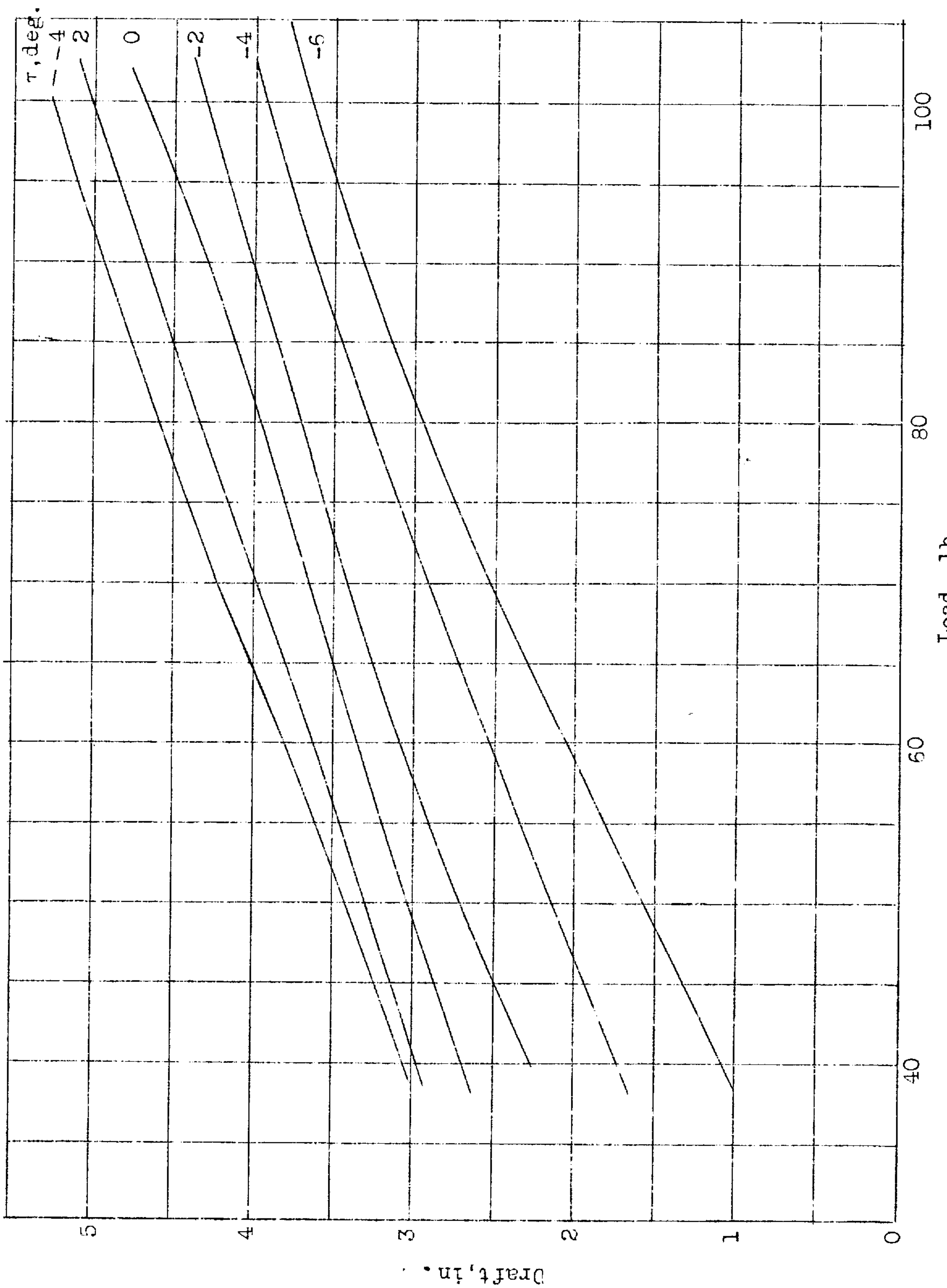


Figure 12.- Model 46. Static drafts.

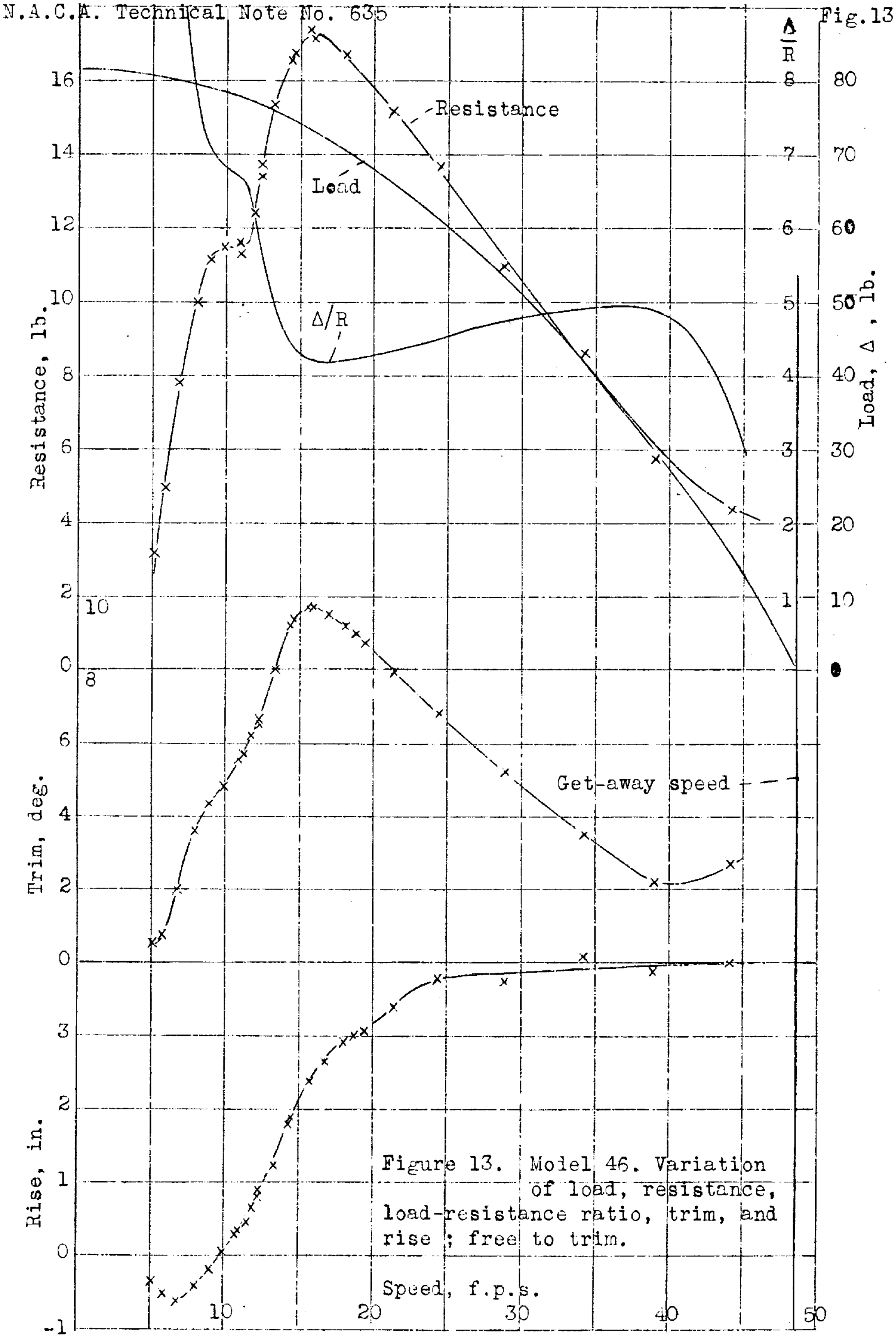


Figure 13. Model 46. Variation of load, resistance, load-resistance ratio, trim, and rise; free to trim.

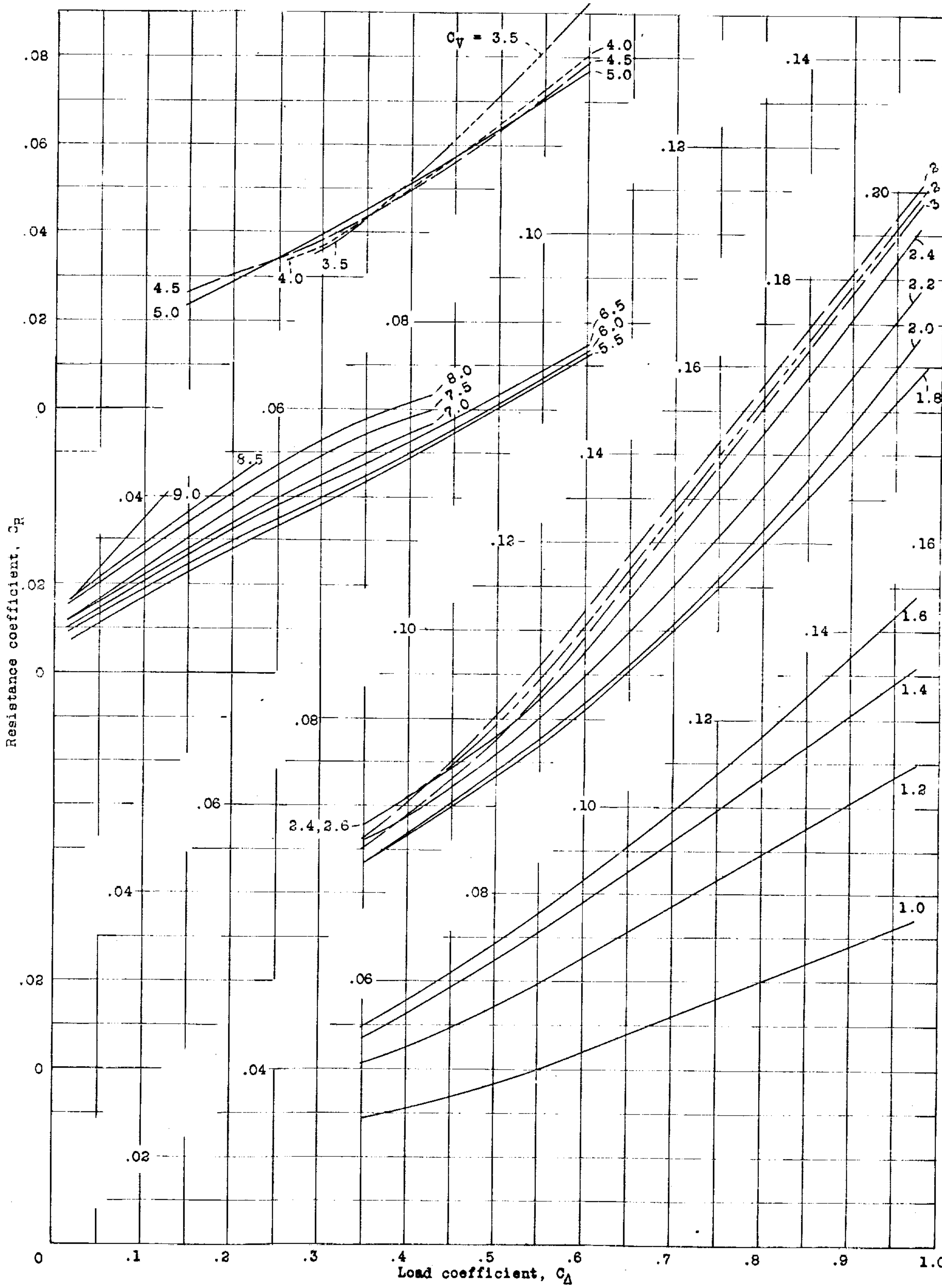


Figure 14. - Model 46. Variation of C_R with C_Δ at best trim.

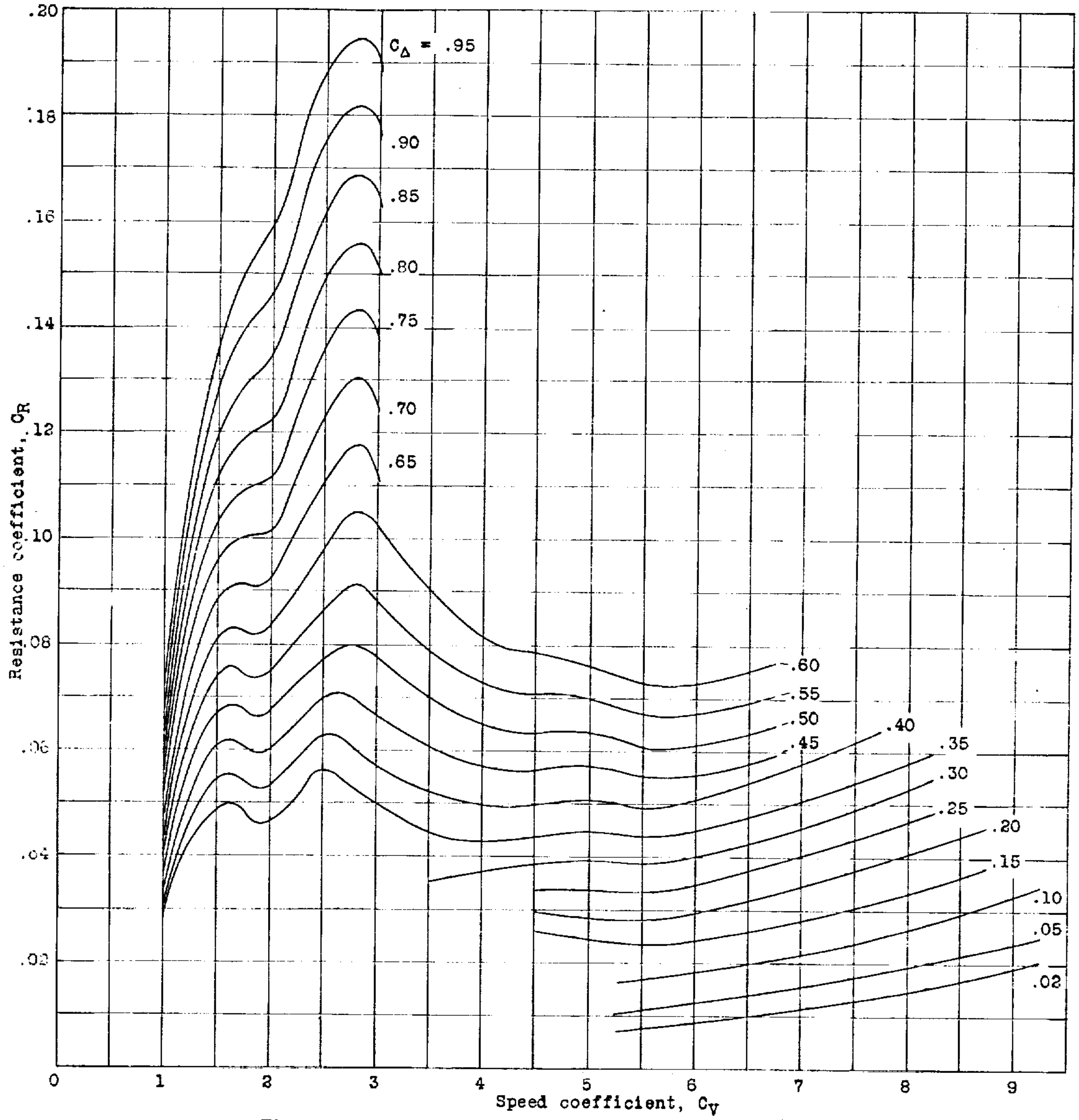


Figure 15. - Model 46. Variation of C_R with C_V at best trim.

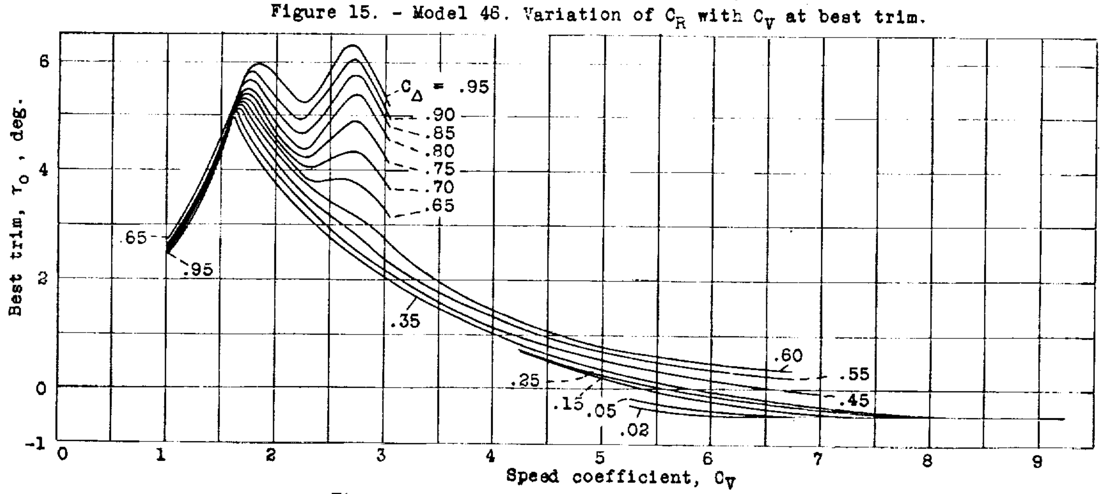


Figure 16. - Model 46. Variation of τ_o with C_V.

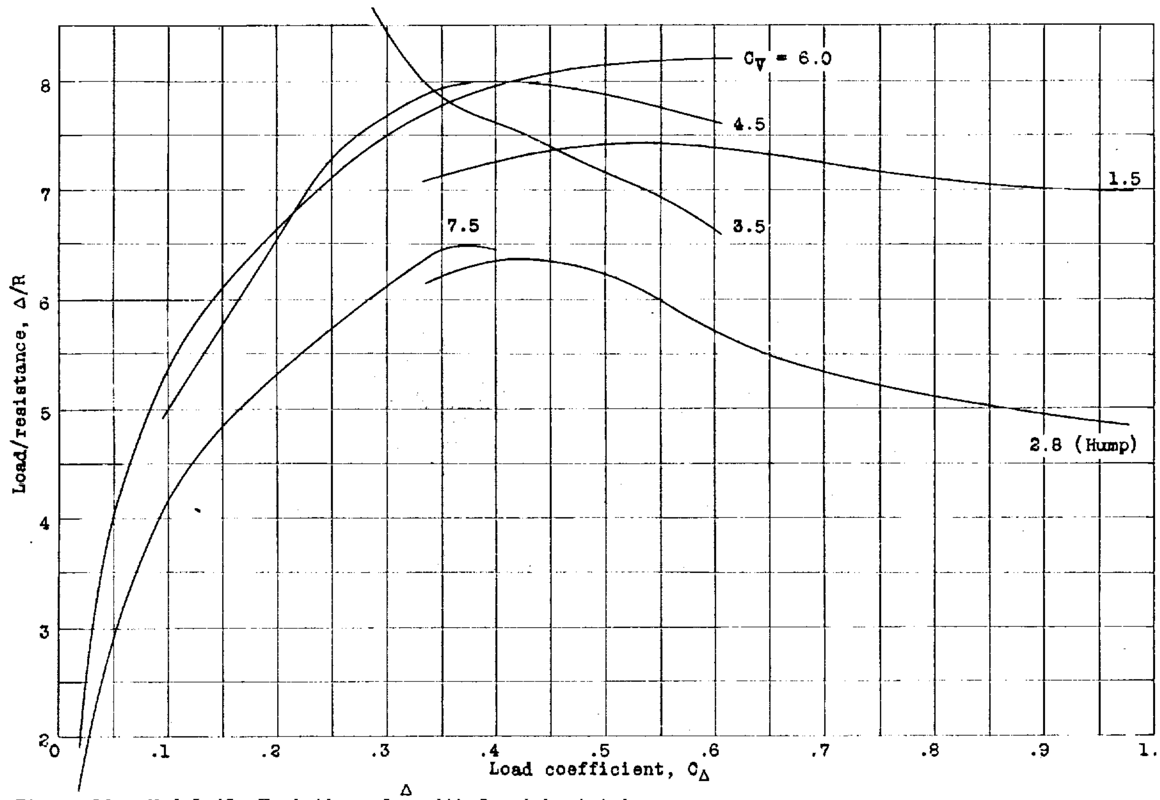
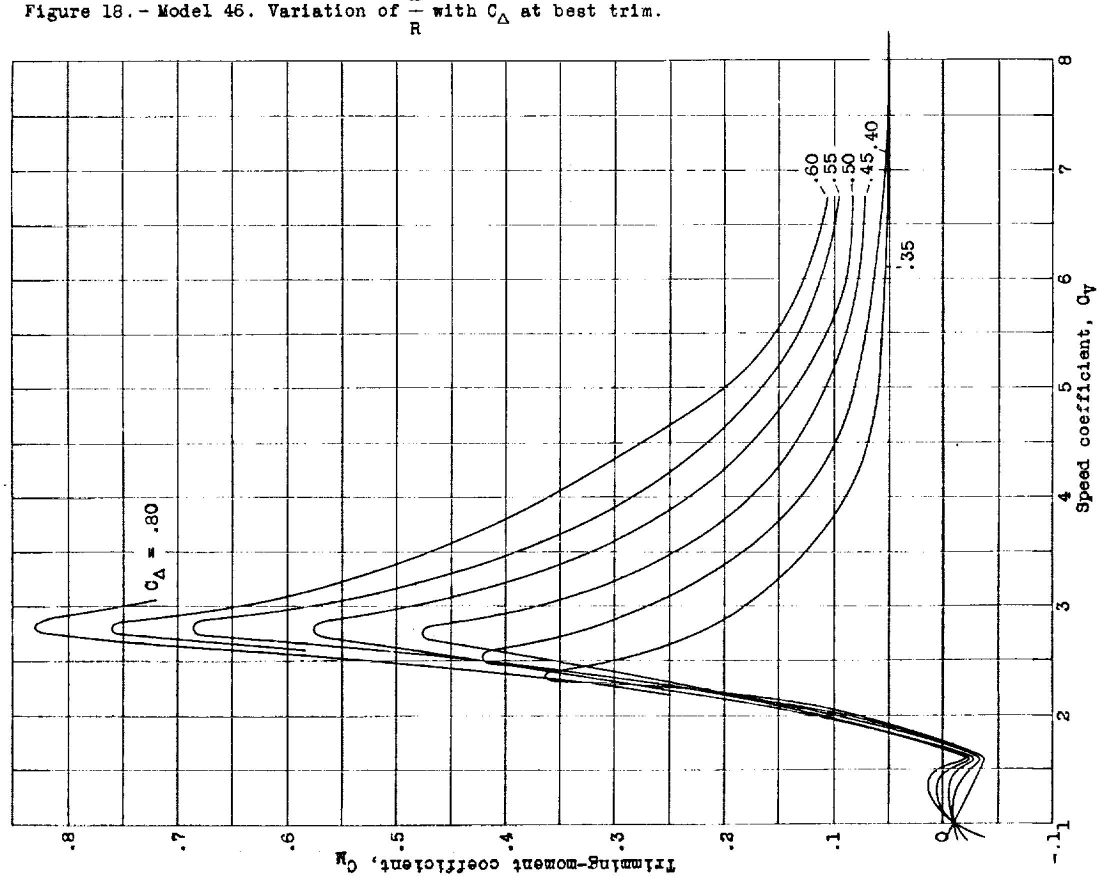
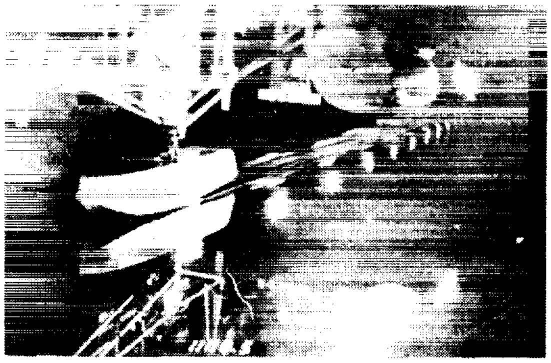


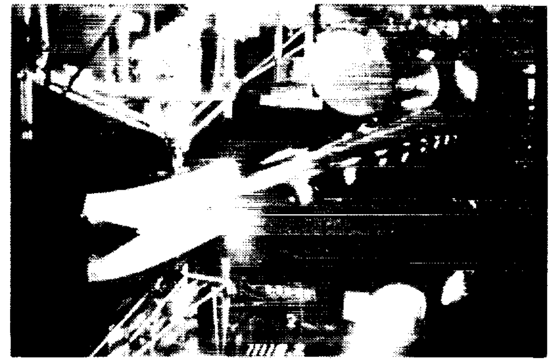
Figure 18.- Model 46. Variation of $\frac{\Delta}{R}$ with C_Δ at best trim.



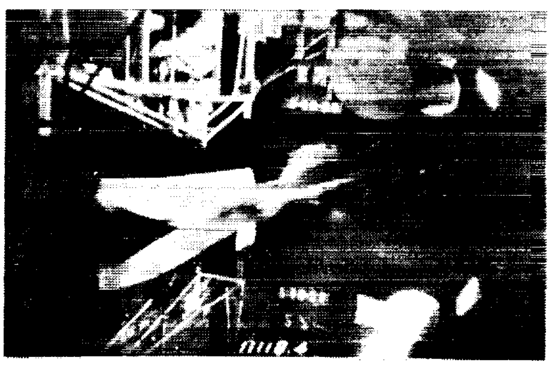
Fifure 17. - Variation of C_M with C_V at best trim.



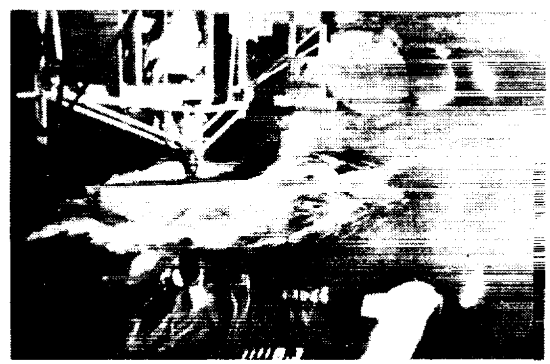
(a) 34.7 f.p.s., $\tau = -1^{\circ}$,
Δ = 5 lb.



(b) 24.2 f.p.s., $\tau = -1^{\circ}$,
Δ = 40 lb.



(c) 16,75 f.p.s., $\tau = 3^{\circ}$,
Δ = 40 lb.



(d) 18.6 f.p.s., $\tau = 5^{\circ}$,
Δ = 100 lb.

(e) 16.75 f.p.s., $\tau = 3^{\circ}$,
Δ = 40 lb.

(f) 18.6 f.p.s., $\tau = 5^{\circ}$,
Δ = 100 lb.

Figure 19.- Spray photographs of model 46

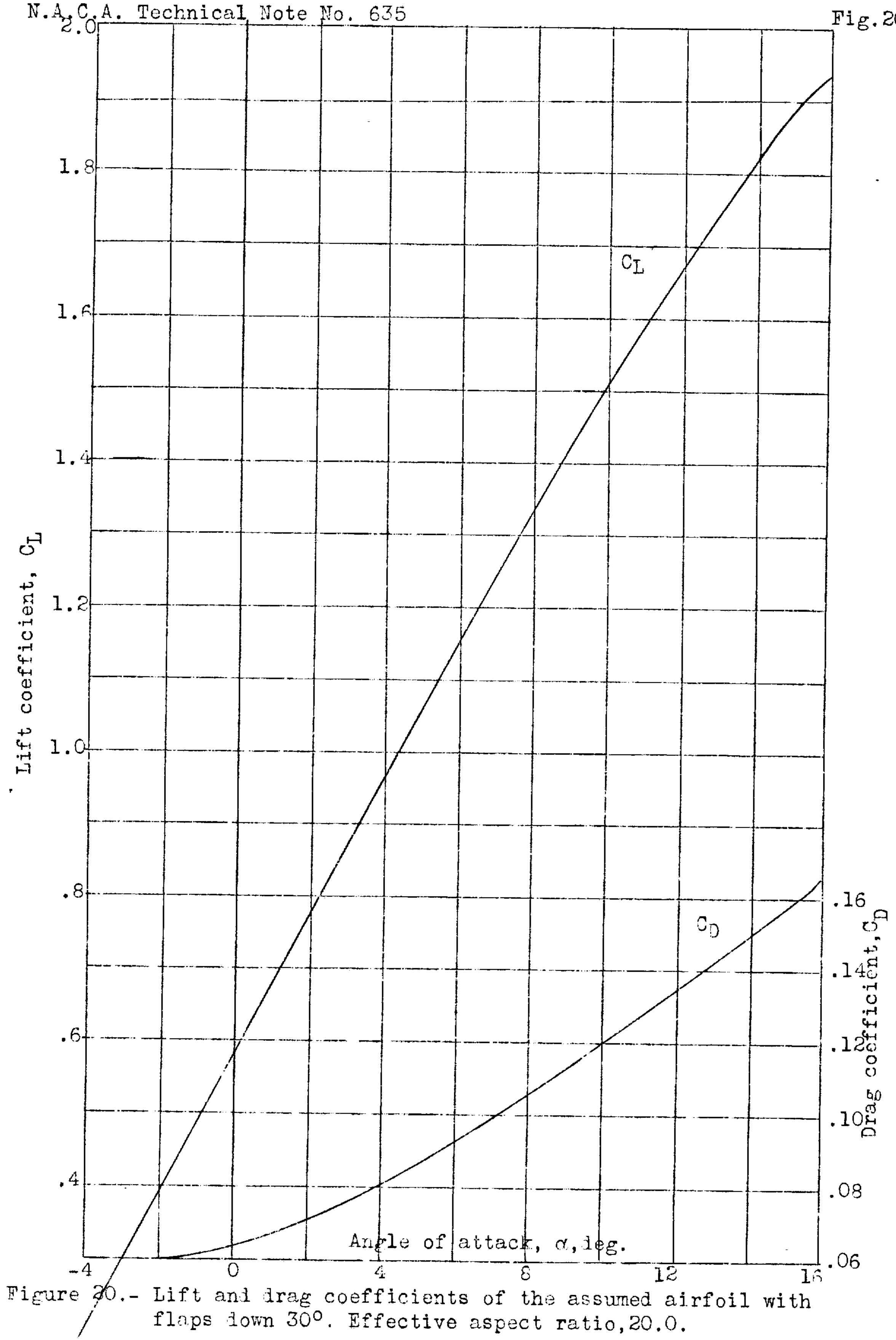


Figure 20.- Lift and drag coefficients of the assumed airfoil with flaps down 30°. Effective aspect ratio, 20.0.

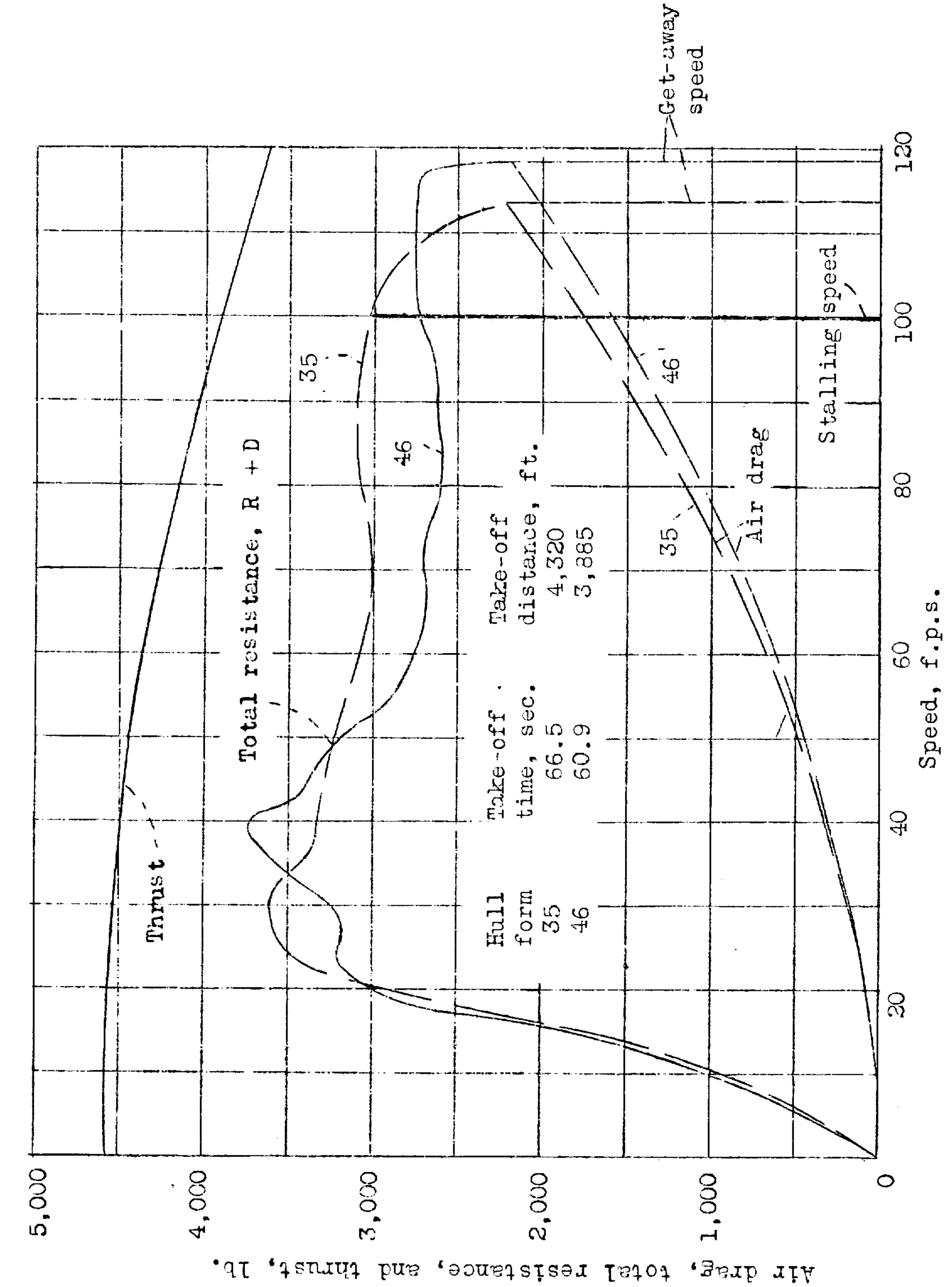


Figure 21. – Take-off comparison of 23,500-lb. flying boats, having twin hulls with the lines of models 35 and 46